International Journal of Power Electronics and Drive Systems (IJPEDS)
Vol. 13, No. 2, June 2022, pp. 856~864
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v13.i2.pp856-864

Design a photovoltaic simulator system based on two-diode model with linear interpolation method

Lam Quang Thai, An Thi Hoai Thu Anh
Department of Electrical Engineering, Faculty of Electrical-Electronic Engineering, University of Transport and Communications, Hanoi, Vietnam

Article Info

Article history:

Received Jul 4, 2021
Revised Mar 2, 2022
Accepted Mar 28, 2021

Keywords:

Buck DC-DC converter
Dual-diode model
I-V, P-V characteristics
linear interpolation
Maximum power point
PV emulator

ABSTRACT

For an effective study of photovoltaic (PV) systems, precise current-voltage (I-V), power – voltage (P-V) curves of photovoltaic modules are required. However, conducting experiment on real panels faces with many difficulties such as needing large space, high cost, objective conditions of the environment. Therefore, it is essential to research an emulator producing the I-V, P-V characteristics of a PV system the same as those conducted on a real PV panel. This paper presents a two–diode model simulation replacing a photovoltaic panel to export precise current-voltage (I-V), power – voltage (P-V) curves based on the linear interpolation method. The proposed simulator shows many advantages of subjecting to changes in radiation and temperature. The accuracy of the emulator has been not only verified by the simulation results on Matlab software, but also evaluated, compared with the experiment model. The simulation results have coincided with the experimental ones, the output error of less than 4% is shown in the experiment.

Corresponding Author:

An Thi Hoai Thu Anh
Department of Electrical Engineering, Faculty of Electrical-Electronic Engineering,
University of Transport and Communications
No. 3 Cau Giay, Lang Thuong Commune, Dong Da District, Hanoi, Vietnam
Email: htanh.ktd@utc.edu.vn

1. INTRODUCTION

In recent years, with the rapid depletion of fossil energy sources, serious environment pollution, exploiting alternative energy sources is getting a knotting issue to draw much attention from researchers [1]-[4]. Among renewable energy sources, solar energy plays an important role in the global sustainable energy source growth [5]-[9], especially, in countries with lots of sunshine like Vietnam. Solar energy can be used as an alternative energy source for electrical one without destroying the environment, little maintenance. However, applying the solar energy in practice has some disadvantage, for examples, performance of PV cell is low, the precision of the photovoltaic (PV) model is not high. Particularly, the accurate PV cell modeling helps significally to analyze PV system performance [9]. There are many models that have been introduced, such as single diode model including a current source in parallel to a diode which is simple but serious disadvantage when the temperature is various [10], and another model - dual diode model owning better accuracy at low irradiance levels which makes it easier for a more accurate prediction of PV system performance [11].

Therefore, to model the correct PV is mainly based on the correct determination of the parameters of the panels. In addition, the parameter identification is very necessary for simulating, evaluating performance [12], [13]. In addition, it has implications for application design in manufacturing and monitoring maximum

power point tracking (MPPT) [14]-[20]. Since the importance of determining PV parameters is receiving increasing attention, a lot of research has been done to develop viable and practical methods to address this problem.

There are many proposed methods of determining the parameters of PV such as analytical methods using a series of complex mathematical equations to derive the parameters of PV [14], [21], [22]. However, these methods also reveal disadvantages such as large computational volume, complex calculations, requiring large computation time, especially when designing a real simulator model must have a microcontroller with extremely fast computational speed and processing time, which results in very expensive design costs [23]. This paper proposes to use the linear interpolation method on the basis of utilizing a DC-DC converter to output the signal to simulate characteristics of I-V, P-V in combination with communication, with the computer for the photovoltaic panel property simulator.

2. PV EMULATOR DESIGN

2.1. A dual-diode model of PV cell and I-V, P-V characteristic plot

Because the I-V, P-V characteristics of the diode match the I-V, P-V characteristics of PV cell module, the PV model is often based on the diode model. There are three PV cell models: Single diode model (SDM) [10], dual diode model (DDM) [22], and triple diode model (TDM) [23], [24]. SDM has simple control structure, low circuit cost, but I-V characteristic curve is less accurate, lack of stable performance under partial shading conditions, unstable to the low radiation region. DDM owns curve accuracy is higher; satisfactory performance under standard test conditions; implements hardware easily, but slightly high complexity and implementation cost. While TMD has got the highest I-V curve's accuracy, but modelling is quite complexity, the execution time is longest; implementing the hardware complicatedly. Therefore, the paper focuses on exploiting the dual diode model. The photovoltaic equivalent circuit in the dual diode model is characterized by an equivalent scheme as shown in Figure 1 consisting of a current source, two diodes, two resistors consisting of R_s and R_p. R_s is the equivalent series resistance of the PV array and R_p is the equivalent parallel resistance.

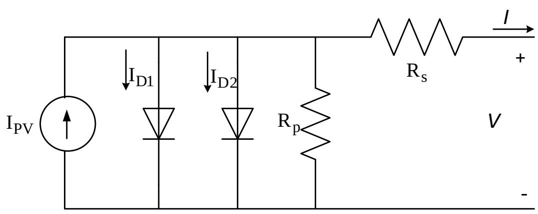


Figure 1. Dual-diode model

Current output I of model shown in Figure 1 is calculated as follow [25]-[27]:

$$I = I_{PV} - I_{01}\left(\exp\left(\frac{V + IR_S}{a_1 V_{T1}}\right) - 1\right) - I_{02}\left(\exp\left(\frac{V + IR_S}{a_2 V_{T2}}\right) - 1\right) - \left(\frac{V + IR_S}{R_P}\right) \tag{1}$$

Where: $V_{T_{1,2}} = \frac{N_S kT}{q}$

I : Output current of Dual-diode model

V : Output voltage of Dual-diode model

I_{pv} : The current generated by the incident light (A)

R_S : The equivalent series resistor (Ω)

R_P : The equivalent parallel resistor (Ω)

a_1, a_2 : Diode's ideality factors (assumed)

$V_{T1,2}$: The thermal voltage

N_s : A number of PV cells connected in series in PV panel

I_{01}, I_{02} : Reverse saturation currents of diode (A)

Q : The electron charge,

k : 1.38×10^{-23} J/K: The Boltzmann constant

R_s *and* R_p is the internal resistance that represents the loss of power during the operation of the photovoltaic.

Plotting the I-V curve needs dealing with (1), but some unknown parameters $I_{p_v}, I_{01}, I_{02}, R_s, R_p$ require to be specified from equations:

$$I_{01} = I_{02} = I_o \frac{I_{PV-STC} + K_i \Delta_T}{exp(V_{os-STC} + \frac{K_V \Delta_T}{(a_1+a_2).V_T} - 1)} \tag{2}$$

$$I_{p_{v_n}} = \frac{R_p + R_s}{R_p} I_{s_{c_n}} \tag{3}$$

$$P_{m_{a_{x_e}}} = V_{mp} . I_{mp} \tag{4}$$

$$I_{pv} = (\mathrm{I}_{pvn} + K_i.\Delta_T)\frac{G}{G_n} \tag{5}$$

$$I_{sc} = (\mathrm{I}_{scn} + K_i.\Delta_T)\frac{G}{G_n} \tag{6}$$

$$R_p = \frac{\mathrm{V}_{mp} + I_{mp}.R_s}{I_{pv} - I_o.\left(\exp\left(\frac{(\mathrm{V}_{mp} + I_{mp}.R_s)}{V_T}\right) + \exp\left(\frac{(\mathrm{V}_{mp} + I_{mp}.R_s)}{(P-1).V_T}\right) - 2\right) - \frac{P_{max,e}}{V_{mp}}} \tag{7}$$

$$R \frac{V_{mp}}{I_{s_{c_n}} - I_{mp}} \frac{V_{o_{c_n}} - V_{mp}}{I_{mp}}_{pmin} \tag{8}$$

$$I_0 = \frac{I_{PV-STC} + K_i \Delta T}{exp\left((V_{oc-STC} + K_V \Delta T / a.V_T) - 1\right)} \tag{9}$$

With $\Delta T = T - T_n$

Where,

I_{scn} : Nominal short circuit current (from datasheets)
V_{ocn} : Nominal open circuit voltage (from datasheets)
I_{mp} : Maximum power point current (from datasheets)
V_{mp} : Maximum power point voltage (from datasheets)
I_{PV-STC} : The current generated by the incident light under standard test conditions
V_{OC-STC} : Open circuit at standard test conditions
$P_{max,e}$: Maximum output peak power of array (calculating)
K_i : The short circuit current coefficient (from datasheets)
K_v : The open circuit voltage coefficient (from datasheets)
T : Actual temperature of PV array in Kelvin (measuring)

T_n : Nominal operating temperature of PV array in Kelvin (from datasheets)

Using the Newton–Raphson iterative method determines R_s, R_p of the mathematical (1). This method requires that the initial value of R_s be chosen to approximate 0, meant that choosing $R^0{}_S = 0$ [28]. The next value of R_S is calculated based on the (10).

$$R_s^{i+1} = R_s^i + \frac{f(R_s^i)}{f'(R_s^i)} \tag{10}$$

Convergence is achieved when $R_s^{i+1} \approx R_s^i$ with an acceptable degree of error, and R_p is calculated as (8). Detecting I_{pv}, I_{o1}, I_{o2}, I_0 from (2) to (9) equations is presented in the algorithm flowchart of Figure 2. After determining unknown parameters of dual diode model from flowchart in Figure 2, it is easy to plot I-V, P-V characteristic curves.

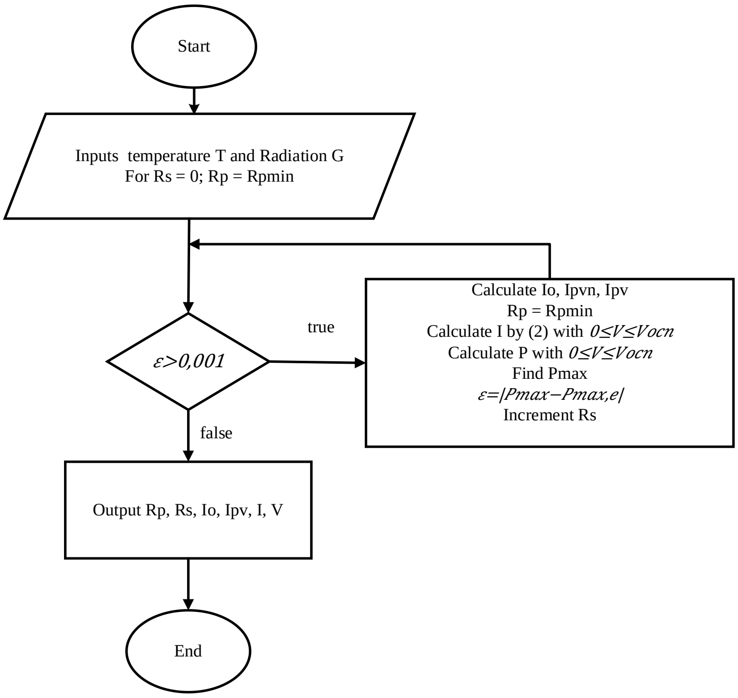


Figure 2. Flowchart to find parameters

2.2. I-V curve linearization

In part 2.1, I-V, P-V characteristic curves of photovoltaic module have been plotted, but these curves are nonlinear owing to their highly dependent on T temperature and G solar radiation. Therefore, the practical implementation will be very complex because a number of points are very enormous, the memory of microcontroller is limited. To solve the above problems, the linear interpolation method is used by taking some special points shown in Figure 3 to design the controller for the power converter system in Figure 4. By implementing this method, the system uses less memory and doesn't spend much time searching for active points, but still ensures the accuracy of the system.

In Figure 3, the I-V curve can be analyzed into three regions: region A, region B and region C in which region B is the strong nonlinear region [29]. The linear interpolation method applied here to linearize the I-V curve is based on the segmentation principle. This method divides I-V curve into four linear intervals.

Four linear segments represented by four equations are calculated as follows:

$$I = I_2 - I_2 \frac{V - V_2}{V_{OC} - V_2} \; with \; V_2 \le V \le V_{0C} \tag{11}$$

$$I = I_{mp} + (I_2 - I_{mp})\left(\frac{V - V_{mp}}{V_2 - V_{mp}}\right) \quad with \quad V_{mp} \leq V \leq V_2 \tag{12}$$

$$I = I_1 + (I_{mp} - I_1)\left(\frac{V - V_1}{V_{mp} - V_1}\right) \quad with \quad V_1 \leq V \leq V_{mp} \tag{13}$$

$$I = I_{sc} + (I_1 - I_{sc})\left(\frac{V}{V_1}\right) \quad with \quad 0 \leq V \leq V_1 \tag{14}$$

Where: $V_1 = \dfrac{V_{oc}}{2}$; $V_2 = \dfrac{V_{oc} + V_{mp}}{2}$

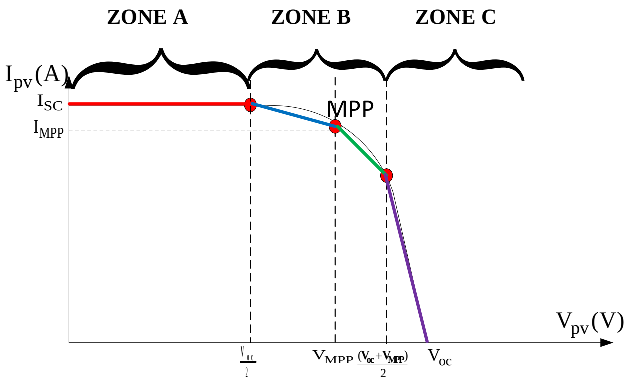


Figure 3. Linearized I-V curve

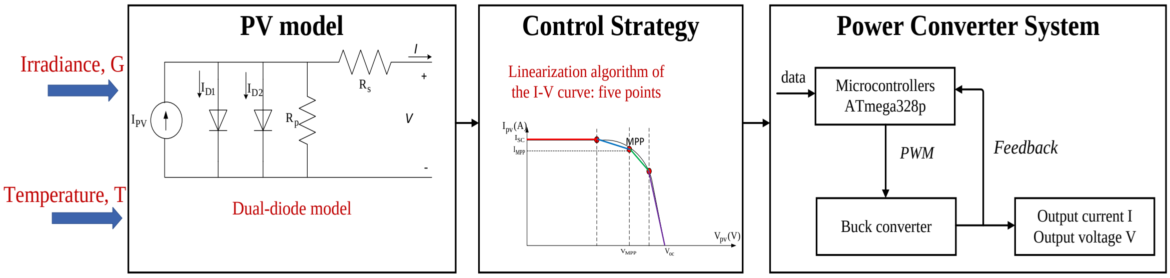


Figure 4. Schematic of the proposed photovoltaic simulator system

3. THE PROPOSED SIMULATOR TOPOLOGY

To verify the correctness of the theoretical studies, in this section, the PV simulator model designed consists of 3 main parts [30] the first part is the PV model; the second part of the PV emulator is the control strategy; the third one of the PV emulator is power converter system, which shown in Figure 4. To control the photoelectric simulation system, using Atmega328p microcontroller has function of outputting control pulse with frequency of 50 kHz to Buck DC-DC converter and measuring the signal transmitted from the current sensor. Buck converter creates current characteristic, corresponding to load. Load uses a variable resistor to characterize the load. a microcontroller whose function is to measure output values of voltage or current, then calculate and give appropriate control signals for the DC-DC converter and communicate with computer to receive input parameters and output data as required by simulation system.

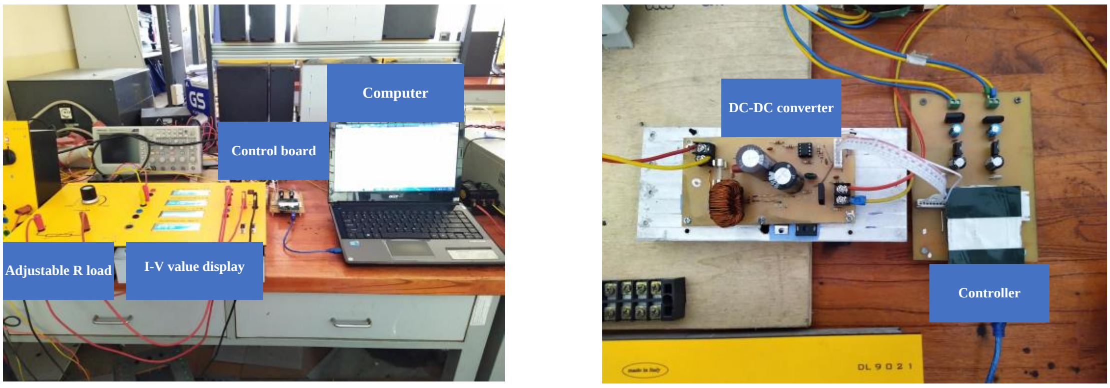
4. SIMULATION AND EXPERIMENT RESULTS

In order to verify theoretical research results, the experimental test bench of PV emulator system is demonstrated in Figure 5. In Figure 5(a) are devices used to build up the system, including PC, control board, display screen of current, voltage and load R. In Figure 5(b) is a detailed picture of the control board comprising of the pulse generator control circuit and the dc-dc converter. The system to conduct the simulation test for the MSX60 solar arrays elected with the rating table from the manufacturer is shown in Table 1.

From the parameters of MSX60 panels given by the manufacturer in Table 1, simulations on matlab software with the modeling of PV panel by double diode model have obtained I-V, P-V characteristic curves shown in Figures 6 and 7. When changing the temperature (250 °C, 350 °C, 450 °C, 550 °C, 650 °C) and keeping the radiation constant (G=1000W/m^2), the I-V and P-V characteristic curves of the panel have demonstrated in Figure 6, and changing radiation characteristics: 100 W/m^2, 200 W/m2, 300 W /m^2, 400 W/m^2, 500 W/m^2, 600 W/m^2, 700 W/m^2, 800 W/m^2, 1000 W/m^2, keeping the temperature at 300 °C, the I-V and P-V characteristic curves of the panel have demonstrated in Figure 7.

Table 1. Table of parameters of the MSX60 solar arrays

Parameters	Speed (rpm)	Parameters	Speed (rpm)
V_{mp}	17.1 (V)	I_{sc}	3.8 (A)
I_{mp}	3.5 (A)	N_s	36
P_{max}	60 (W)	K_i	0.003 (A/K)
V_{oc}	21.1 (V)	K_v	-80e-3 (V/K)10



(a) (b0

Figure 5. The experimental test bench: (a) interior of a manufactured photovoltaic simulator (b) control of board

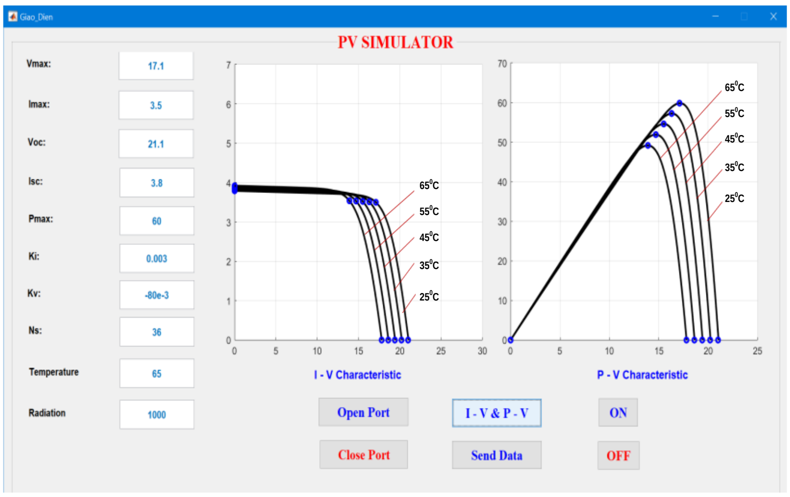


Figure 6. The I-V curve variation according to the temperature of the emulated PV module MSX60 (T=25 °C, 35 °C, 45 °C, 55 °C, 65 °C; G=1000 W/m^2)

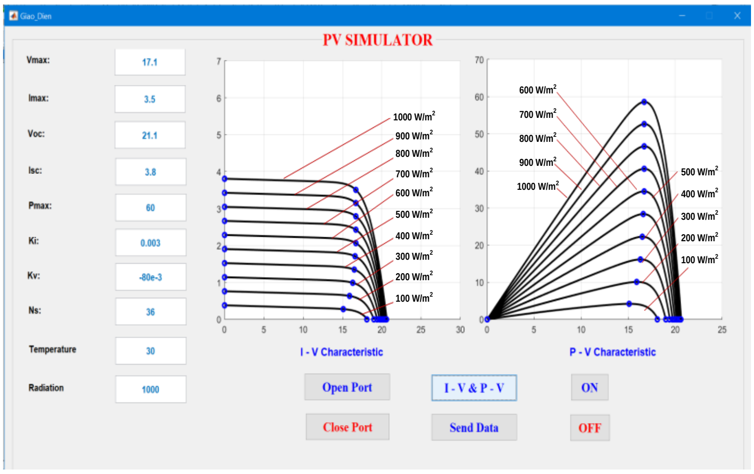


Figure 7. The I-V curve variation according to the radiation of the emulated PV module MSX60 (G=100 … 1000 W/m^2; T=30 ℃)

When connecting to the hardware to sample and change the loads by changing the variable resistor, we get the corresponding working points. The transmitted data is processed by the software and represented by pink points running on the I-V, P-V characteristics of the photovoltaic panel. The actual measured values of current I and voltage V of the resistive load R indicate that the working points in pink lie on the I-V, P-V characteristic curves of the simulated MSX60 panel shown Figures 8 and 9. The working points closely track the real curves, which proves that the simulator has accurately simulated the characteristics of real PV panels. Figures 8 and 9 also show the working points located on the I-V, P-V characteristic curves of the MSX60 panel and the actual measured values of current I and voltage V of the load on experimental model are the same with the same environmental conditions: G=1000 W/m^2, T=25 ℃, and resistive load changing from $1\Omega\ to\ 15\Omega$.

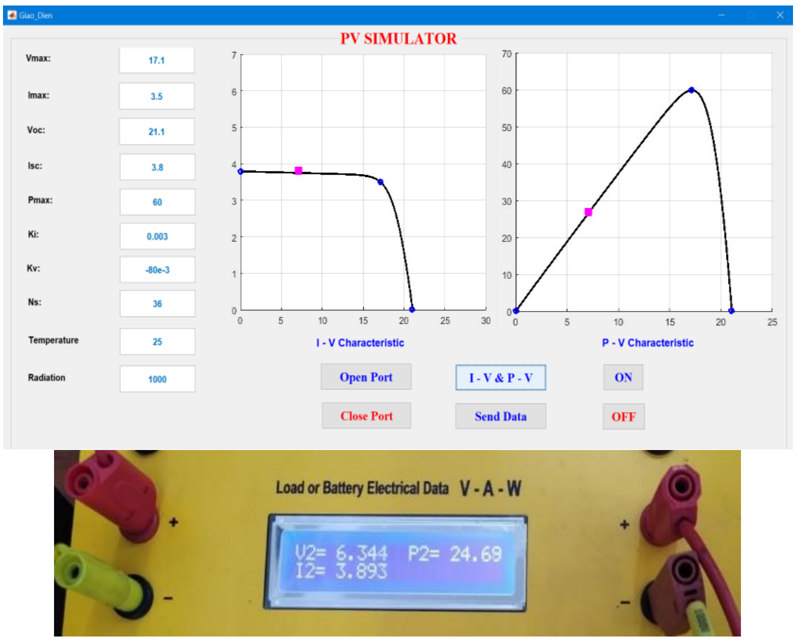


Figure 8. Placement of the operating point on the I-V curve under meteorological conditions: G=1000 W/m^2, T=25 ℃

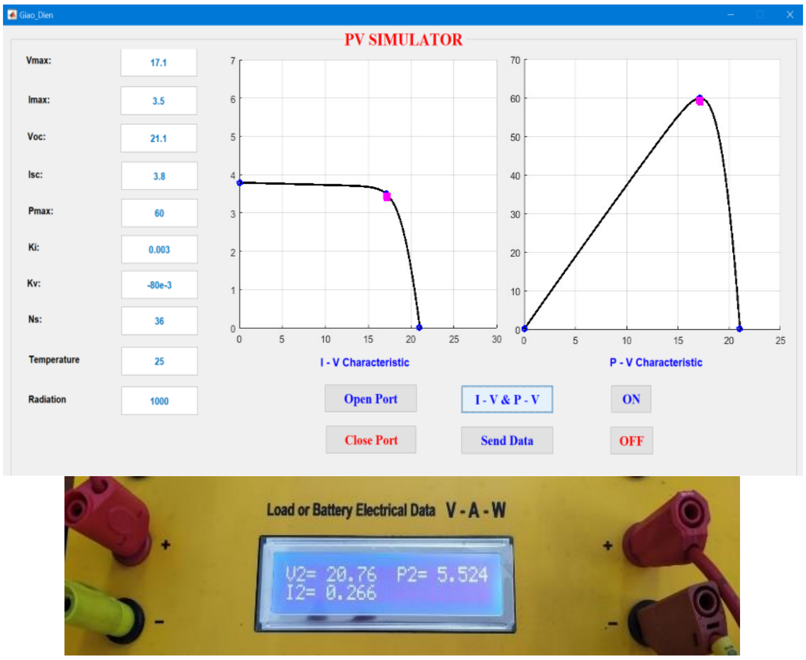


Figure 9. Placement of the operating point on the I-V curve under meteorological conditions: G=1000 W/m^2, T=25 ℃

5. CONCLUSION

In the paper, a simulator is designed to simulate the I-V, P-V characteristics of PV panels. This study not only proposes a mathematical model of PV based on a double-diode model with high accuracy under low radiation conditions, but also designs a controller that applies linear interpolation method to control the Buck converter to output I - V, P-V characteristics like the output of the actual photovoltaic panel, and can communicate, control and analyze by software installed on the computer. The accuracy of the proposed system has been evaluated and compared with the actual data from the photovoltaic panel manufacturer MSX-60 with the output error ranging from 1 to 4% shown in the experiment. On the other hand, the simulator can adjust quickly and accurately, and can self-adjust by the I-V curve of the photovoltaic panels closely the actual conditions: radiation and temperature based on the capability of controller reprogrammable so that characteristic simulation can be applied to many different photovoltaic panels on the market today.

REFERENCES

[1] S. W. Liao, W. Yao, X. Han, J. Wen, and S. Cheng, “Chronological operation simulation framework for regional power system under high penetration of renewable energy using meteorological data,” *Applied Energy*, vol. 203, pp. 816–828, Oct. 2017, doi: 10.1016/j.apenergy.2017.06.086.

[2] B. Yang, T. Yu, H. Shu, J. Dong and L. Jiang, “Robust sliding-mode control of wind energy conversion systems for optimal power extraction via nonlinear perturbation observers,” *Applied Energy*, vol. 210, pp. 711–723, Jan. 2018, doi: 10.1016/j.apenergy.2017.08.027.

[3] B. Yang, *et al.*, “Passivity-based sliding mode control design for optimal power extraction of a PMSG based variable speed wind turbine,” *Renewable Energy*, vol. 119, pp. 577–589, Apr. 2018, doi:10.1016/j.renene.2017.12.047.

[4] S. Ghazali and R. Nazir, "Performance and energy saving analysis of grid connected photovoltaic in West Sumatera," *International Journal of Power Electronics and Drive Systems*, vol. 7, no. 4, pp. 1348-1354, 2016, doi: 10.11591/ijpeds.v7.i4.pp1348-1354.

[5] J. Liu, J. Wen, W. Yao, and Y. Long, “Solution to short-term frequency response of wind farms by using energy storage systems,” *IET Renew Power Gener*, vol. 5, pp. 669–78, 2016, doi: 10.1049/iet-rpg.2015.0164.

[6] J. Liu *et al.*, "Impact of Power Grid Strength and PLL Parameters on Stability of Grid-Connected DFIG Wind Farm," *IEEE Transactions on Sustainable Energy*, vol. 11, no. 1, pp. 545-557, Jan. 2020, doi: 10.1109/TSTE.2019.2897596.

[7] G. Li, G. Li, and M. Zhou, “Model and application of renewable energy accommodation capacity calculation considering utilization level of interprovincial tie-line,” *Protect Control Modern Power Syst*, vol. 4, pp. 1-12, Jan. 2019, doi: 10.1186/s41601-019-0115-7.

[8] L. M. Tuan and M. T. T. Huong, “Implementation of electrical power consumption monitoring system by using wireless sensor network and IoT,” *Transport and Communications Science Journal*, vol 71, no. 3, pp. 274-284, 2020, doi: 10.25073/tcsj.71.3.11.

[9] C. Vimalarani and N. Kamaraj, “Modeling and performance analysis of the solar photovoltaic cell model using embedded MATLAB,” *Simulation*, vol.91, no3, pp.217–232, 2015, doi: 10.1177/0037549714568535.

[10] A .M. Humada, M. Hojabri, S. Mekhilef, H. M. Hamada, “Solar cell parameters extraction based on single and double-diode models,” *Renew Sustain Energy Rev*, vol.56, pp. 494–509, Apr.2016, doi: 10.1016/j.rser.2015.11.051.

[11] A. Abbassi, R. Gammoudi, M. A Dami, O. Hasnaoui, M. Jemli, “An improved single-diode model parameters extraction at different operating conditions with a view to modeling a photovoltaic generator: A comparative study,” *Sol Energy*, vol.155, pp. 478–89, Oct. 2017, doi: 10.1016/j.solener.2017.06.057.
[12] J. Chen, W. Yao, C-K. Zhang, Y. Ren, L. Jiang, “Design of robust MPPT controller for grid-connected PMSG-Based wind turbine via perturbation observation based nonlinear adaptive control,” *Renewable Energy*, vol. 134, pp. 478–495, Apr. 2019, doi: 10.1016/j.renene.2018.11.048.
[13] A. R. Jordehi, “Parameter estimation of solar photovoltaic (PV) cells: A review,” *Renewable Sustainable Energy Reviews*, vol. 61, pp. 354–371, Aug. 2016, doi: 10.1016/j.rser.2016.03.049.
[14] R. Majdoul, E. Abdelmounim, M. Aboulfatah, A. W. Touati, A. Moutabir and A. Abouloifa, "Combined analytical and numerical approach to determine the four parameters of the photovoltaic cells models," *2015 International Conference on Electrical and Information Technologies (ICEIT)*, 2015, pp. 263-268, doi: 10.1109/EITech.2015.7162977.
[15] S. Koohi-Kamali, N. A. Rahim, H. Mokhlis, and V. V. Tyagi, “Photovoltaic electricity generator dynamic modeling methods for smart grid applications: A review,” *Renewable Sustainable Energy Reviews*, vol. 57, pp.131–172, 2016, doi: 10.1016/j.rser.2015.12.137.
[16] M. A. Abdourraziq, M. Maaroufi, "Experimental Verification of the main MPPT techniques for photovoltaic system." *International Journal of Power Electronics and Drive Systems*, vol. 8.1, pp. 384-391, Mar.2017.
[17] M. Elyaqouti, S. Hakim, S. Farhat, L. Bouhouch, A. Ihlil , "Implementation in Arduino of MPPT using variable step size P&O algorithm in PV installations," *International Journal of Power Electronics and Drive Systems*, vol. 8, no. 1, pp. 384-391, 2017, doi: 10.11591/ijpeds.v8.i1.pp384-391.
[18] O. M. Benaissa, S. Hadjeri, and S. A. Zidi, "Modeling and simulation of grid connected PV generation system using Matlab/Simulink," *International Journal of Power Electronics and Drive Systems*, vol. 8, no. 1, pp. 392-401, 2017, doi: 10.11591/ijpeds.v8.i1.pp392-401.
[19] T. O. Ahmed, O. O. Ogunleye, A. Y. Abdulrahaman, N.Alu, “Dye sensitized solar cell (dsc) based on reduced graphene oxide (rgo)-tio2nanocompositephotoelectrode and polyaniline (pani) counter electrode,” *Transport and Communications Science Journal*, vol. 71, no. 7, pp. 789-801, 2020, doi: 10.25073/tcsj.71.7.
[20] T. V. Khoi, A. T. H.T. Anh, and D. V. Phuc, “Optimizingthe urban trainspeed to minimize the energy consumption and comfort,” *Transport and Communications Science Journal*, vol 72, no. 3, pp. 317-329, 2021, doi: 10.47869/tcsj.72.3.7.
[21] M. Kumar and A. Kumar, “An efficient parameters extraction technique of photovoltaic models for performance assessment,” *Sol Energy*, vol. 158, pp.192–206, 2017, doi: 10.1016/j.solener.2017.09.046.
[22] R. Abbassi, A. Abbassi, M. Jemli, and S.Chebbi, “Identification of unknown parameters of solar cell models: A comprehensive overview of available approaches,” *Renew Sustain Energy Rev*, vol 90, pp. 453–74, 2018, doi: 10.1016/j.rser.2018.03.011.
[23] V. Khanna, B. K. Das, D. Bisht, and P. K. Singh, “A three diode model for industrial solar cells and estimation of solar cell parameters using PSO algorithm,” *Renewable Energy*, vol. 78, pp.105–113, 2015, doi: 10.1016/j.renene.2014.12.072.
[24] D. Allam, D. A. Yousri, M. B. Eteiba,“Parameters extraction of the three diode model for the multi-crystalline solar cell/ module using Moth-Flame optimization algorithm,” *Energy Convers Manage*, vol. 123, pp. 535–548, 2016, doi: 10.1016/j.enconman.2016.06.052.
[25] K. Ishaque, Z. Salam, H. Taheri, and A. Shamsudin, “A critical evaluation of EA computational methods for photovoltaic cell parameter extraction based on two diode model,” *Solar Energy*, vol. 85, no. 9, pp.1768–1779, 2011, doi: 10.1016/j.solener.2011.04.015.
[26] E. Q. B. Macabebe, C. J. Sheppard, and E. E. Van Dyk, “Parameter extraction from I-V characteristics of PV devices,”, *Solar Energy*, vol. 85, no. 1, pp.12–18, 2011, doi: 10.1016/j.solener.2010.11.005
[27] M. El Azzaoui, H. Mahmoudi, K. Boudaraia, "Backstepping control of wind and photovoltaic hybrid renewable energy system," *International Journal of Power Electronics and Drive Systems*, vol.7, no. 3, pp. 677-686, Sep. 2016, doi: 10.11591/ijpeds.v7.i3.pp677-687.
[28] A. Hussein, “A simple approach to extract the unknown parameters of PV modules,” *Turkish Journal of Electrical Engineering & Computer Sciences*, vol. 25, pp. 4431-4444, 2017, doi: 10.3906/elk-1703-14
[29] H. Messaoudi, A.B.A.Bennani, N. M. Bellaaj, and M. Orabi, “Design and implementation of a solar PV emulator,” *IREEC1 Refrigeration Energy and Environment, Hammamet*, 2016.
[30] R. Ayop and C. W. Tan, “A comprehensive review on photovoltaic emulator,” *Renewable and Sustainable Energy Reviews*, vol. 80, pp. 430–452, 2017, doi: 10.1016/j.rser.2017.05.217.

BIOGRAPHIES OF AUTHORS

Lam Quang Thai . received his Engineer (2018) degrees in Control Engineering and Automation from University of Transport and Communications (UTC), and completed Master of Science (MSc) in 2021 from the Ho Chi Minh City University of Technology and Education (HCM-UTE) in Electrical Engineering. Now, he is a lecturer of Department of Electrical and Electronics Engineering under University of Transport and Communications – Campus in Ho Chi Minh City (UTC2), Vietnam. His current interests include Automation Control solutions applied for Industry and transportation, renewable energy, artificial intelligence (AI). He can be contacted at email: lqthai@utc2.edu.vn.

An Thi Hoai Thu Anh received her Engineer (1997), MSc (2002) degrees in Industrial Automation Engineering from Hanoi University of Science and Technology, and completed PhD degree in 2020 from University of Transport and Communications (UTC). Now, she is a lecturer of Faculty of Electrical and Electronic Engineering under University of Transport and Communications (UTC). Her current interests include power electronic converters, electric motor drive, saving energy solutions applied for industry and transportation. She can be contacted at email: htanh.ktd@utc.edu.vn.